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AIR POLLUTION INDICES IN THE UNITED STATES AND CANADA-- THE PRESENT PICTURE

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Symposium on A Recommended Standard Air Pollution Index

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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Air Pollution Indices in the United States and Canada--the Present Picture

Wayne R. Ott* and Gary C. Thom**

ABSTRACT

Although several air pollution indices have been proposed in the technical literature, there has been no systematic evaluation of the many indices that are presently being used for daily air quality reporting in metropolitan areas. A literature review and user survey were therefore conducted by CEQ and EPA to develop a compendium of air pollution indices. This compendium describes the index-reporting practices of all U.S. and Canadian air pollution control agencies which employ more than ten staff persons. In the United States, 35 out of 55 agencies were found to be using some kind of air pollution index. For each of the indices, separate analysis records were prepared to summarize index characteristics and code them into a classification system. Through this system, it was determined that 14 basically different types of indices are currently in use. Except for five States which have adopted internally uniform index formats, no two U.S. cities are presently using the same index. The indices differ in the numbers and types of pollutants included, the methods of calculation, and the descriptor words which are reported with the index values. From these findings, along with comments received from air pollution control agencies as part of the survey, it was concluded that there is need to develop a Standard Air Pollution Index which can be recommended for use by State and local agencies.

I. INTRODUCTION

In recent years, dozens of States and municipalities throughout the United States have responded to public information needs by developing and adopting various kinds of daily air pollution indices. The news media have widely reported these indices, with the result that most of the air quality information now provided to the general public is communicated in the form of

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an air quality index. Thus, a wealth of experience now exists in using air pollution indices for public reporting.

An "air pollution index" is a scheme that translates the (weighted) values of individual air pollution-related variables (for example, carbon monoxide concentration or visibility) into a single number or set of numbers. The purpose of these indices has been to achieve parsimony and simplicity by using a mathematical manipulation to express air pollutant concentrations in a manner easily understood by the layman.

A total of 10 air pollution indices have been proposed in the scientific literature.[1-9] Many more have come into common use by metropolitan air pollution control agencies. Why have so many indices been proposed? What are the characteristics of these indices? To what extent have the indices proposed in the literature been adopted for common use on a daily basis? Do any common characteristics emerge from the many indices in existence?

II. STUDY APPROACH

To answer these and other related questions, we undertook a detailed study of existing air pollution indices--those appearing in the literature and those currently used in metropolitan areas. To gain information on daily indices, we conducted a survey of air pollution control agencies. The survey population, consisting of 55 city and county air pollution control agencies with 10 or more staff members (Table I), was selected from the 1973-74 Directory of Air Pollution Control Agencies published by the Air Pollution Control Association.[10] State agencies known to operate air pollution index systems and Canadian Provinces also were surveyed.

Telephone calls were made to these agencies from August to December 1974 soliciting information on the nature and characteristics of each agency's air pollution index, if any. Of the 55 U.S. agencies contacted, 28 supplied

staffs greater than 10

City/County	Agency Size	Material Received	Index In Use	Comments
Birmingham, AL	17	•		
Phoenix, AZ	25	•		Discontinued Index
Anaheim, CA	24		•	Replaced Index
Los Angeles, CA	380	•	•	Replaced Index
Riverside, CA	26			
San Bernardino, CA	53			
San Diego, CA	53			
San Francisco, CA	220	•	•	Replaced Index
[a] Denver, CO	54	•	•	
[b] New Haven, CN	11	•	•	Replaced Index
[b] Washington, DC	14	•	•	
Bradenton, FL	11			
Jacksonville, FL	15	•	•	
Miami, FL	50	•	•	
Sarasota, FL	21			
Tampa, FL	16	•	•	
Atlanta, GA	14	•	•	
Chicago, IL	175	•	•	
Gary, IN	18			
Indianapolis, IN	15			
Louisville, KY	39	•	•	
[a] Baltimore, MD	90	•	•	Replaced Index
[b] Montgomery Co., MD	10		•	
[a] Boston, MA	87	•		
Springfield, MA	12			
Detroit, MI	77	•	•	
[b] St. Paul, MN	13	•	•	
Kansas City, MO	15			
St. Louis, MO	35			
Albuquerque, NM	15			
[b] Albany, NY	237		•	
[b] Buffalo, NY	44	•	•	
[b] Mineola, NY	37		•	
New York City, NY	382		•	
[b] Rochester, NY	12		•	
Charlotte, NC	14			
[b] Akron, OH	13		•	
[b] Cincinnati, OH	65	•	•	Replaced Index
[b] Cleveland, OH	80	•	•	
[b] Dayton, OH	45		•	Replaced Index
[b] Toledo, OH	25		•	
Oklahoma City, OK	15	•		Discontinued Index
[a] Portland, OR	20	•	•	
Philadelphia, PA	94	•	•	Replaced Index
Pittsburgh, PA	82	•	•	
Chattanooga, TN	22		•	
Memphis, TN	14		•	
Nashville, TN	17	•	•	
Dallas, TX	21	•	•	
El Paso, TX	10			
Houston, TX	76	•		
Pasadena, TX	45			
[b] Fairfax Co., VA	12		•	
Seattle, WA	39	•	•	
Milwaukee, WI	25			

[a] City index is operated by State but is not part of State-wide index system

[b] City index is part of State-wide or regional index system

written material, and other information was obtained by telephone. Typically, the material covered the nature of the index, its manner of calculation, and the way in which it is reported.

These sources enabled us to assemble a large and extensive library of information on existing air pollution indices. The following discussion presents highlights from our analysis of this data base. The study findings are reported in greater detail in "Air Pollution Indices: A Compendium and Assessment of Indices Used in the United States and Canada."[11]

III. FINDINGS

The literature review revealed that little had been published about air pollution indices in routine daily use by metropolitan air pollution control agencies. Furthermore, the ten indices reported in the scientific literature have not received widespread use by air pollution control agencies. Of the 55 metropolitan air pollution agencies surveyed, 35 (64 percent) use an air pollution index. Five States and two Canadian Provinces operate State-wide (or Province-wide) index systems. Within each State/Province index system, many cities use the same index. Most indices were implemented since 1970.

In the course of our study, we found that all air pollution indices could be compared on three basic characteristics:

- Number of Variables
- Method and Mode of Calculation
- Descriptor Categories

To facilitate comparisons among indices, we developed an index classification system that uses a four character code. For example, the Oak Ridge Air Quality Index (ORAQI)[6] is coded as "$5A_3A$." The number "5" indicates that the index includes five pollutants or other variables; "A_3" denotes the method and mode

of calculation (i.e., it is nonlinear and the variables are combined to give one index value); "A" referes to the basis for the descriptor categories. A "descriptor category" is the interpretive word reported along with the index (for example, "good," "unhealthful," "clean air").

Using this classificaiton system, the characteristics of the existing air pollution indices reveal striking variation. When all index characteristics are shown on the same table a "shotgun" pattern emerges (Table II). Except for the States or Provinces, where many cities may use the same index, no two indices are exactly the same. However, analysis of the index characteristics does reveal some interesting results.

Index Variables. We found that the majority of the air pollution indices appearing in the literature incorporate five of the six pollutants for which National Ambient Air Quality Standards (NAAQS) exist (excluding hydrocarbons). Sulfur dioxide (SO_2) appears most often, while Coefficient of Haze (COH, paper tape sampler measure of particulate) is least common (Table III). Compared to indices in common use, indices appearing in the literature are more likely to include other measures of air pollution (industrial emissions, fuel burned, and visibility, etc.).

Table III.

Number of Indices Using Selected Air Pollution Variables

	Variables						
Source	CO	SO_2	NO_2	OX	COH	TSP	Other
10 Indices in the Literature	7	8	6	7	4	7	4
35 City/County Indices	26	26	16	20	22	11	2
8 State/Province Indices	6	8	3	5	6	2	0
53 Total Indices	39	42	25	32	32	20	6
Percent of Indices	75%	79%	47%	60%	60%	38%	11%

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TABLE II

SUMMARY OF INDEX CLASSIFICATION RESULTS

SOURCE	VARIABLES							CALCULATION METHOD				INDEX			DESCRIPTOR CATEGORIES			
															TYPE			NUMBER
	CO	SO_2	NO_2	O_3	COH	TSP	OTHER	A	B	C	D	1	2	3	A	B	B	
LITERATURE																		
[redacted][1]		•			•			•						•					
M.U.R.C.[2]					•			•				•					•	1
COMBUSTION PRODUCTS[3]							•			•		•					•	1
AIR QUALITY INDEX[4]	•	•	•	•		•				•		•					•	[redacted]
CHICAGO[5]	•	•	•	•		•	•			•				•			•	[redacted]
ARAC[6]	•	•	•	•		•	•			•				•			•	[redacted]
SEXTON[7]	•	•	•	•		•		•						•	•			1
EVI[8]	•	•		•		•		•						•	•			
STARAMS[9]	•	•	•	•	•	•	•							•	•			
CANADIAN[10]	•	•	•	•	•	•	•	•		•		•		•	•			1
[redacted]																		[redacted]
[redacted]																		
[redacted]																		
[redacted]																	

In contrast, the U.S. city/county indices in common use show a distinct preference for COH as a measure of particulate matter--all but two of the 35 city/county air pollution indices (94 percent) incorporate particulate matter, either COH or high volume sampler total suspended particulate (TSP), with COH twice as common. The next most common index pollutants are carbon monoxide (26 agencies, 74 percent), sulfur dioxide (26 agencies, 74 percent), oxidant (20 agencies, 57 percent), and nitrogen dioxide (16 agencies, 46 percent). One city/county index includes visibility and another incorporates particle scattering alone.

Overall, the city/county indices differ greatly in the number of variables they include (see Table IX); some include two or less variables (6 percent), some include three variables (20 percent), and the greatest number choose four variables (23 percent).

The eight State/Province indices, each of which may serve many cities, include pollutants which are similar to those used by the city/county agencies. Among the States and Provinces, however, there is a distinct preference for COH over TSP; six of the eight State/Province agencies include COH, and two include TSP as measures of particulate.

If the variables for all the air pollution indices are listed in order of occurrence, the most common pollutants are particulate matter (TSP and COH), followed by sulfur dioxide (SO_2), carbon monoxide (CO), and oxidant (O_x), with nitrogen dioxide (NO_2) the least common variable.

Method and Mode. Three calculation methods, plus reporting of actual concentrations, were used to classify air pollution indices:

A. Nonlinear

B. Segmented Linear

C. Linear

D. Actual Concentrations

A nonlinear calculation method consists of one or more variables raised to an exponent. The segmented linear calculation method consists of two or more straight line segments jointed at successive (x,y) coordinates, or "breakpoints" (Figure 1). The linear method is the simple ratio between the pollutant's concentration and some fixed number (e.g., the standard) giving a fraction or percentage.

The term calculation mode was introduced to denote the way the agency reports the pollutants or variables:

1. Individual - every variable is reported.
2. Maximum - only the maximum variable is reported.
3. Combined - the variables are combined in some fashion.

The majority of the indices published in the literature (6 of 10) use a nonlinear (Type A) calculation method (Table IV). None reports actual concentration data, and only one uses the segmented (Type B) linear function. The combined (Type 3) calculation mode appears most frequently (7 of 10 indices), and no index uses the maximum (Type 2) calculation mode (Table V).

Table IV

Calculation Methods of Air Pollution Indices

Source	Nonlinear (A)	Segmented Linear (B)	Linear (C)	Actual Concentrations (D)
10 Indices in the Literature	6	1	3	0
35 City/County Indices	4	13	7	11
8 State/Province Indices	3	3	0	2
53 Total Indices	13	17	10	13
Percent of Indices	25%	32%	19%	23%

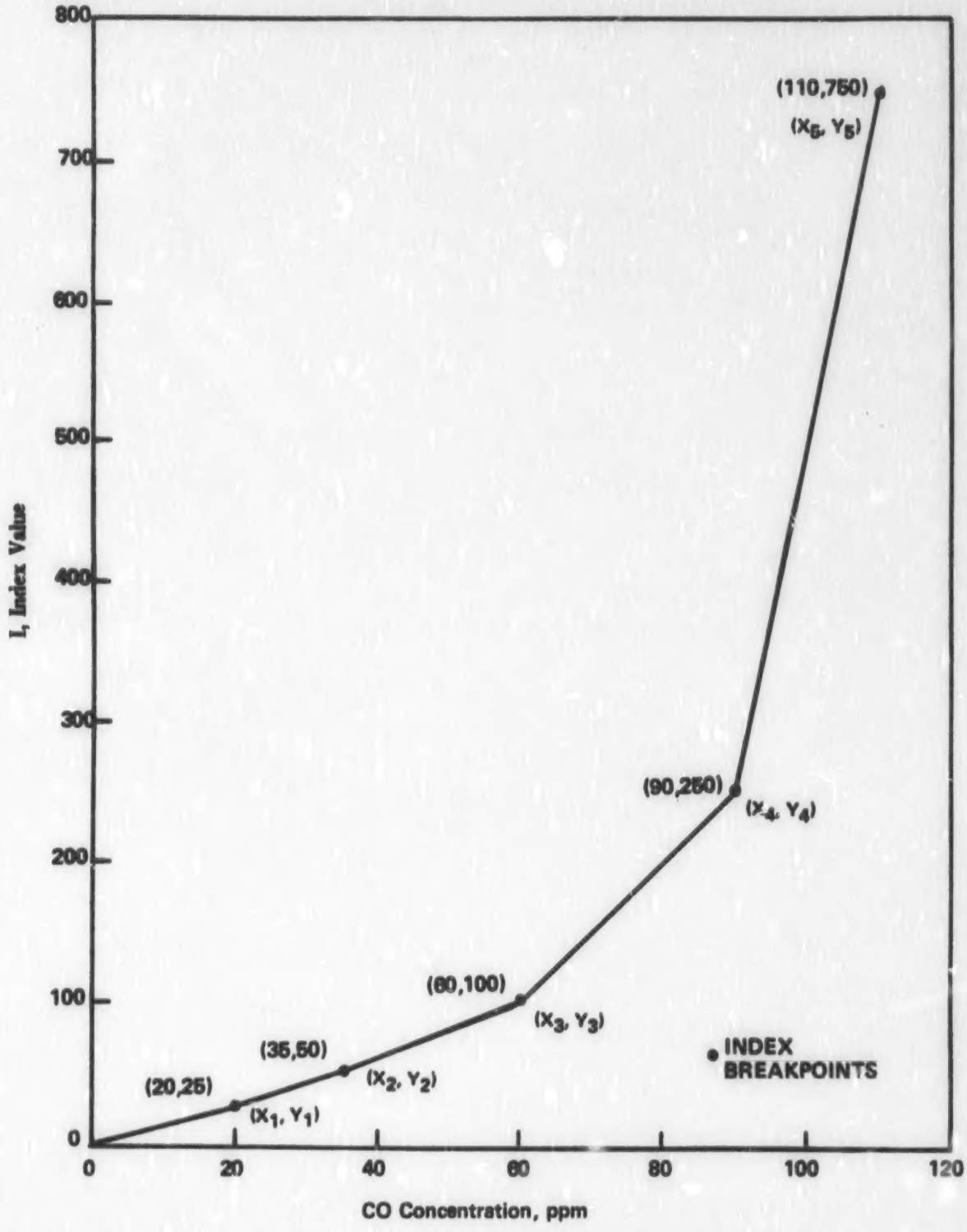

Figure 1. Example of a segmented linear function for carbon monoxide

Table V

Calculation Modes of Air Pollution Indices

Source	1. Individual	2. Maximum	3. Combined
10 Indices in the Literature	3	0	7
35 City/County Indices	12	15	8
8 State/Province Indices	3	3	2
53 Total Indices	18	18	17
Percent of Indices	34%	34%	32%

By contrast, a majority of the U.S. city/county agencies favor the linear (Type B or C) calculation methods (20 out of 35 agencies). Only four of 35 agencies use a nonlinear calculation method, and approximately one-third (11 of 35 agencies) report actual concentration values.

The calculation methods for the State/Province indices are divided equally among nonlinear, segmented linear, and actual concentration values, with none choosing the purely linear calculation method. Similarly, the State/Province indices are divided equally among the individual, maximum, and combined calculation modes. However, the nonlinear, combined indices appear more frequently in the Canadian indices, while the States prefer the simpler linear, uncombined calculation methods and modes.

When all air pollution indices are considered together, the most common index structure is the segmented linear function (32 percent) and over half (51 percent) the air pollution indices in existence use either a linear or segmented linear calculation method. In general, the metropolitan air pollution agencies (city, county, State, and Province) tend to use either segmented linear functions or actual concentration values instead of the more complicated nonlinear indices usually proposed in the literature. The city/

county agencies also are more likely to use the simpler individual or maximum calculation modes, while those in the literature generally use the combined mode.

Descriptor Categories. Three general classes of descriptor categories were identified:

A. Based on Ambient Air Quality Standards

B. Based on Standards and Episode Criteria

C. Arbitrary

The results of classifying index categories are shown in Table VI. Air pollution indices reported in the literature have descriptor categories that are based either on ambient air quality standards (Type A) or are arbitrary (Type C), but none are based on the standards and episode criteria (Type B).

Table VI

Descriptor Categories of Air Pollution Indices

Source	A	B	C
10 Indices in the Literature	5	0	5
35 City/County Indices	6	19	10
8 State/Province Indices	2	5	1
53 Total Indices	13	24	16
Percent of Indices	25%	45%	30%

By constrast, the greatest share of air pollution indices used by city/county agencies have descriptor categories that are based on standards and episode criteria. The State indices show a similar pattern.

Overall, when all the air pollution indices are considered together, the greatest percentage (45 percent) base descriptor categories on ambient air quality standards and episode criteria.

The number of descriptor categories used in air pollution indices greatly varies (Figure 2), particularly for indices in current use. Among the city/county air pollution agencies, the most common number of descriptor categories is four (23 percent), and the majority of agencies (60 percent) use from three to five descriptor categories. The State and Province index systems, like the city/county agencies, also tend to use three to five descriptor categories. Although most of the air pollution agencies use fewer than five descriptor categories, a total of 44 different descriptor words were identified (Table VII).

IV. DISCUSSION

This study has shown that existing air pollution indices generally include one or more of the five NAAQS air pollutants (excluding hydrocarbons). The most common pollutant is particulate matter (either as COH or TSP), and NO_2 is least common. Although a majority of the indices published in the literature (60 percent) use a nonlinear calculation method, a majority of the U.S. city/county indices favor the simpler linear calculation methods (linear or segmented linear). In the literature, indices also tend to combine variables in some fashion (combined mode), while those in common use in metropolitan areas tend to report the pollutants individually (individual mode) or report only the maximum pollutant (maximum mode). The descriptor words used in city/county air pollution indices usually are based on the ambient air quality standards and episode criteria, and the majority of these indices use from three to five descriptor categories, with four categories the most common.

The variety of air pollution indices in common use is surprising. If the number of descriptor words is neglected, application of the index classification system reveals 14 basically different index types in current use by cities, counties, States, and Provinces (Table VIII). With two

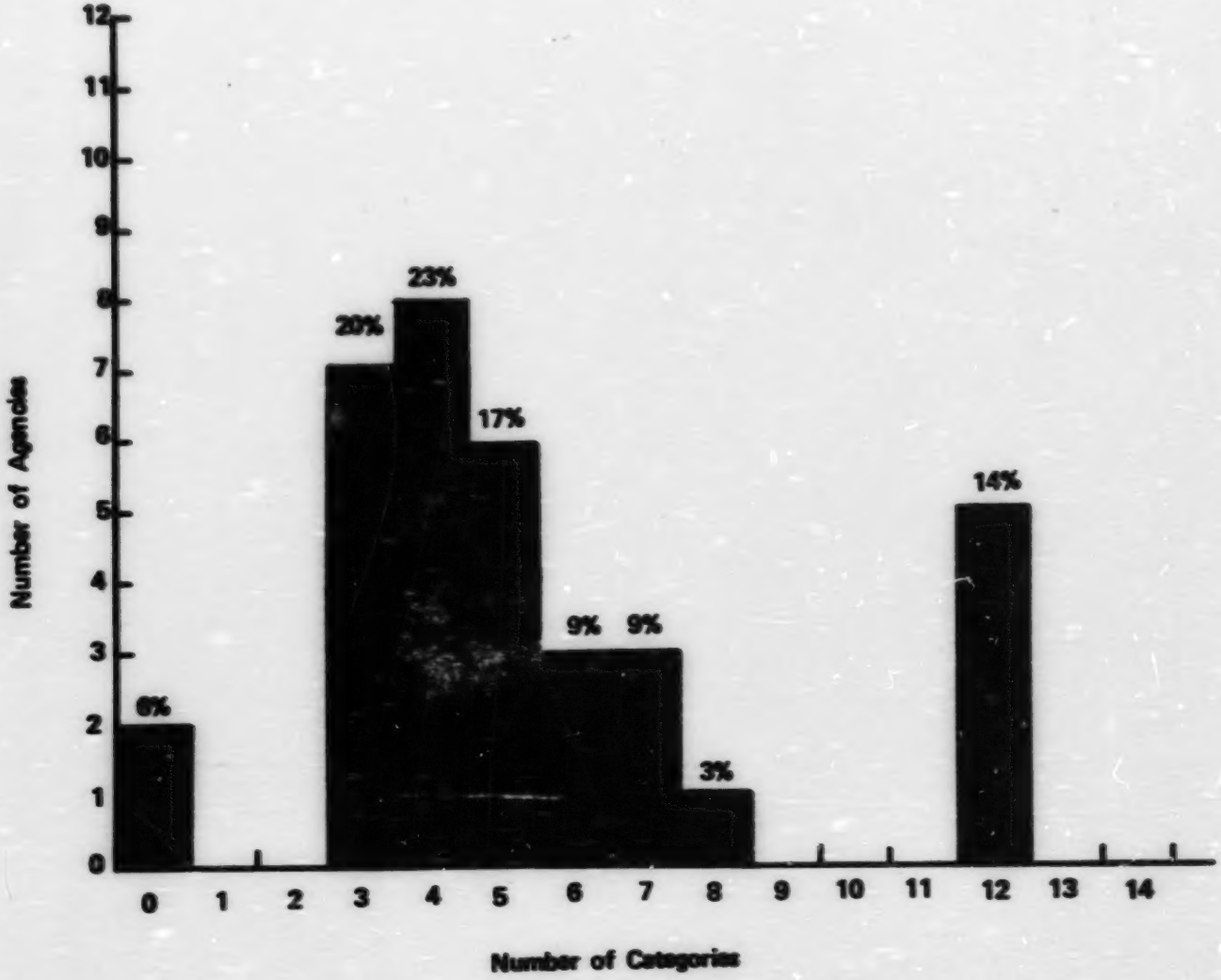

Figure 2. Histogram of the number of descriptor categories used in the 35 U.S. city and county air pollution indices

Table VII.

Frequency Distribution of the 44 Words Used for Descriptor Categories

Heavy	11	Normal	2
Good	10	Stage 1	2
Light	9	Stage 2	2
Moderate	7	Stage 3	2
Unhealthy(ful)	7	Very Heavy	2
Unsatisfactory	7	Warning	2
Emergency	6	Above Average	1
Poor	5	Acute	1
Alert	4	Average	1
Extremely Heavy	4	Below Average	1
Fair	4	Endangerment	1
Medium	4	Extremely Poor	1
Satisfactory	4	Harmful	1
Severe	4	High	1
Clean	3	Red Alert	1
Extremely Light	3	Significant	1
Very Poor	3	Slight	1
Acceptable	2	Very Dangerous	1
Dangerous	2	Very Good	1
Excellent	2	Very Light	1
Hazardous	2	Watch	1
Low	2	Yellow Alert	1

Table VIII.

The 14 Basic Types of Indices and Their Users

Type	Users
A_1C	Detroit, Oklahoma City,[a] Memphis
A_3A	Tampa
A_3B	Minnesota, Ontario
A_3C	Alberta
B_2B	Baltimore,[b] Philadelphia,[b] Seattle, Connecticut,[b] Ohio,[c] Washington, DC
B_2C	Denver
C_1C	Nashville
C_3B	Louisville, Pittsburgh, Dallas
C_3C	Jacksonville, Miami, Atlanta, Phoenix[a]
D_1A	New Jersey, New York State
D_1B	Anaheim,[b] Los Angeles,[b] Chicago
D_1C	Portland, Chattanooga
D_2A	New York City
D_2B	San Francisco[b]

[a] Discontinued index
[b] Replaced index
[c] Replaced index in Cincinnati and Dayton

minor exceptions, when descriptor words are taken into account, no two indices are exactly the same. Each has a different mathematical formulation and a potentially different meaning to the public. Thus, an index value of 100 reported in Washington, D.C., means something entirely different than a value of 100 reported in Cleveland, Ohio.

A possible solution to this problem is the development and adoption, on a nationwide basis, of a uniform air pollution index. As part of the Compendium[11] survey, a case study was undertaken of a three-State metropolitan area (Steubenville-Wheeling-Pittsburgh) where an attempt currently is being made to adopt a uniform air quality index. From this case study and from the opinions and comments received from the 55 air pollution control agency respondents, it was possible to identify 10 criteria that would be desirable in any standardized air pollution index:

- Easily understood by the public
- Includes major pollutants and capable of including future pollutants
- Relates to ambient air quality standards and goals
- Relates to Federal Episode Criteria
- Calculated in a simple manner using reasonable assumptions
- Rests on a reasonable scientific basis
- Not inconsistent with perceived air pollution levels
- Spatially meaningful
- Exhibits day-to-day variation
- Can be forecast a day in advance

In addition to meeting these criteria, any uniform air pollution index that is adopted should possess technical characteristics similar to those shared by the air pollution indices currently in use. The most commonly occurring

characteristics of the U.S. city/county air pollution indices (Table IX) offer a suitable basis for designing a candidate uniform air pollution index that could be adopted on a nationwide scale. Five index variables appear to be the most common choice among air pollution agencies now using indices (37 percent). The segmented linear function appears to be the most commonly selected calculation method (37 percent of the agencies), and the maximum mode is selected over the other two calculation modes (43 percent). Four descriptor categories are used most frequently, and they generally are based on air quality standards and episode criteria.

V. CONCLUSION

Because air pollution indices probably are the most important means by which the general public receives information about air pollution levels in their community, lack of uniformity of these indices can create many problems. Not only does the diversity raise questions about the meaningfulness of today's indices, but an interested member of the public who travels from city to city will readily become confused about air quality levels in each city. Informed members of the public, when they wish to compare air pollution levels in different cities, cannot do so using today's air pollution indices. Regulatory officials, with so many disparate indices in existence, cannot use these numbers to draw a national picture of air pollution levels and trends. Finally, the diversity itself suggests that no consistent scientific rationale has been employed in developing these indices.

A possible solution to this problem is the development and adoption, on a nationwide scale, of a uniform air pollution index. Any uniform index that ultimately is proposed should meet the needs of air pollution agencies which already use indices. Thus, such a uniform index should have characteristics

TABLE IX.
CLASSIFICATION BREAKDOWN
FOR THE 35 U.S CITY/COUNTY AIR POLLUTION INDICES

NUMBER OF VARIABLES	NO.	PERCENT
1	5	14
2	4	11
3	9	26
4	3	9
5	13	37
6	1	3
CALCULATION METHOD		
A. NONLINEAR	4	11
B. SEGMENTED LINEAR	13	37
C. LINEAR	7	20
D. ACTUAL CONCENTRATIONS	11	32
CALCULATION MODE		
1. INDIVIDUAL	12	34
2. MAXIMUM	15	43
3. COMBINED	8	23
DESCRIPTOR CATEGORIES		
A. STANDARDS	6	17
B. STANDARDS AND EPISODE CRITERIA	19	54
C. ARBITRARY	10	29
NO. OF DESCRIPTOR CATEGORIES		
2 OR LESS	2	6
3	7	20
4	8	23
5	6	17
6	3	9
7	3	9
8 OR MORE	6	17

similar to the characteristics shared by the air pollution indices currently used in the cities, counties, States, and Provinces.

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